Workshop on the Science of Fusion ignition on NIF
May 22 – May 24, 2012

http://lasers.llnl.gov/workshops/science_of_ignition/

Panel 4: Stagnation Properties and Burn
Findings and Recommendations

May 24, 2012: Final Panel Outbriefs

Panel 4 Co-Leads:

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The panel 4 was divided into three working groups

0D processes (Charlie Cerjan / Sean Regan et al.)

- Pressure-balance model of the hot spot 2 quad charts
- Transport of radiation, alpha particles etc

1D processes (Warren Garbett / Radha Bahukutumbi et al.)

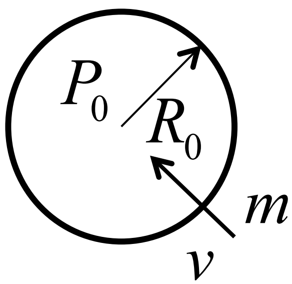
- Uncertainty in the decompression of the inner portion of the shell 1 quad chart
- Implosion trajectory
- M-band and fast-electron preheat
- Non-local ion transport during shock transit in gas

3D processes (Jeremy Chittenden / Dan Sinars et al.)

- Shape/ hotspot topology
- Spatial ρR variations 1 quad chart
- Rayleigh-Taylor, Richmyer-Meshkoff, Deceleration RT
- Shock timing asymmetry
- Generation of vorticity

0D working group

Stagnation pressure can be expressed in terms of initial gas pressure P_0 for an infinitely thin shell with mass m, radius R_0 and velocity v



$$P_{stag} = P_0 \left(\frac{mv^2}{P_0 R_0^3} \right)^{\frac{5}{2}} \qquad P_{stag} \sim \frac{1}{P_0^{\frac{3}{2}}} \sim \frac{1}{\rho_{gas}^{\frac{3}{2}}}$$

1. Causes for low stagnation pressure:
   - DT vapor has higher density than expected.
   - Release of the shell inner surface.
   - Increase of the gas mass due to early mix (for example fill tube).
   - Bremsstrahlung losses not correctly calculated.
2. Causes for lower temperature and density profiles in the hot spot and dense fuel:
   - Inaccurate EOS of the compressed shell in strongly coupled regime.
   - Additional heat-transport mechanisms:
     1. Nonlocal effects
     2. Magnetic fields
     3. Turbulence
     4. Is the shell heat conduction higher than we think?
   - Bremsstrahlung losses and reabsorption in the shell.

0D working group

Stagnation and burn
Stagnation pressure of the hot spot

Underlying physics to be addressed

Causes of low stagnation pressure:

- DT vapor has higher density than expected.
- Release of the shell inner surface.
- Increase of gas mass due to the fill tube.
- Bremsstrahlung losses not correctly calculated.

Learned from NIC

Inferred stagnation pressures are lower than predicted.

Research Directions

- Theory: Develop analytic models.
- Code development: Perform 3D simulation of hot-spot mix mass seeded by measured surface perturbation spectrum.
- OMEGA/NIF experiments: Measure DT vapor pressure; measure fuel and ablator mass mixed into hot spot; measure stagnation pressure.
- Diagnostics: develop nuclear and x-ray techniques to diagnose mix and stagnation pressure.

Outcome and Potential Impact

What would be the impact of a better treatment or understanding of this physics, for the simulation capability, for the design of igniting or burning targets, and/or more broadly?

Achieve higher stagnation pressure.

0D working group

Stagnation and burn
Temperature/density profiles of hot spot/dense fuel layer

Underlying physics to be addressed

Causes of lower temperature/density profiles in hot spot/dense fuel:

- Inaccurate EOS of compressed shell in strongly coupled regime
- Additional heat transport mechanisms:
  - —Nonlocal effects
  - —Magnetic fields
  - —Turbulence
  - —Is shell heat conduction higher than we think?
- Bremsstrahlung losses/reabsorption in the shell

Learned from NIC

Spatial profiles of temperature and density in hot spot and surrounding dense fuel layer are lower than predicted.

Research Directions

- Theory: Develop analytic models.
- Code development: Perform 3-D simulation including nonlocal effects, magnetic fields, and turbulence
- Experiments: Diagnose spatial profiles of plasma conditions in hot spot/dense fuel
- Diagnostics: Develop nuclear/x-ray techniques to diagnose spatial profiles of plasma conditions in hot spot/dense fuel

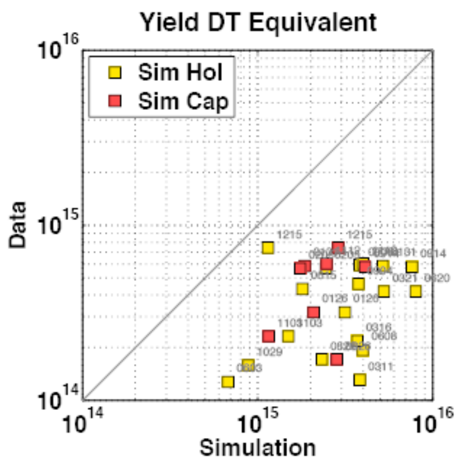
Outcome and Potential Impact

What would be the impact of a better treatment or understanding of this physics, for the simulation capability, for the design of igniting or burning targets, and/or more broadly?

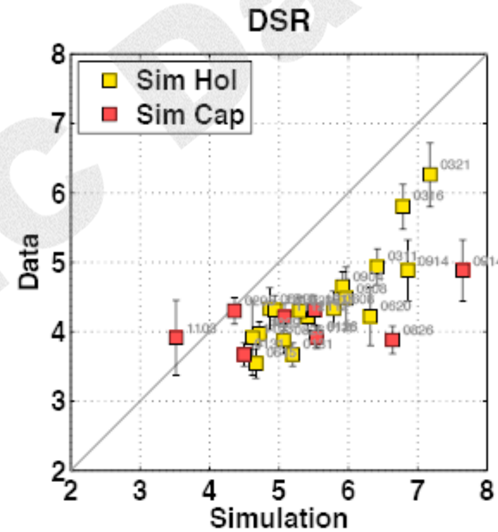
Higher neutron yield and alpha heating.

1D working group

Observations indicate that ρR and hotspot pressures are lower than post-shot simulations

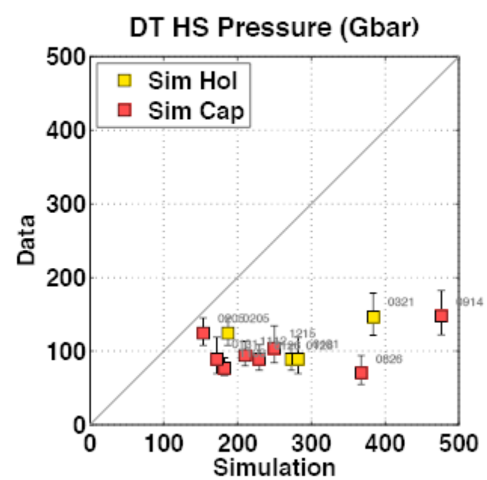


Yields are 3-20 times lower than post-shot simulations.



Inferred ρRs are ~15% lower than post-shot simulations

Inferred hotspot pressures are 2-5 times lower than post-shot simulations.



Figures from NIF data archive

Could 1D effects explain the low observed/inferred hot-spot pressures and ρRs?

Possible 1D causes could be due to:

1. **Uncertainty in the decompression of the inner portion of the shell.**
   - Shock mistiming due to drive uncertainties.
   - Fast-electron preheat (perhaps amplified by density modulations due to 3D effects?).
2. **Treatment of the shock front.**
   - Non-local transport during shock transit in the gas.
   - Use of artificial viscosity.
   - Non-Spitzer electron-ion equilibration
3. **Incomplete elimination of the coasting phase.**
4. **Uncertainties in the DT EOS at high densities and low-temperatures (weakly degenerate and moderately coupled conditions).**
5. **Possible uncertainty in initial DT radial composition due to fractionation.**

1D working group

Stagnation and Burn
Uncertainty in the shell decompression

Underlying physics to be addressed

What is the 1D density profile before the onset of deceleration? The inner portion of the shell can be decompressed if the -

- Shock catch-up occurs well inside the shell.
- Non-local transport of ions during shock transit heats the inner surface of the shell.
- Fast-electron preheat of the shell.

Learned from NIC

- Inferred hot-spot pressure is lower than simulated even when calculations correct for shock timing and implosion velocity.
- ρR is ~85% of the PT design.
- ρR can be reduced if the inner shell is decompressed when the shock returns from the center.

Research Directions

What can be done near term?

- Calculate non-local ion transport during shock transit in the gas.
- Layered keyhole experiment with a witness plate to measure inner surface release.
- Study scaling of hotspot pressure with implosion velocity.

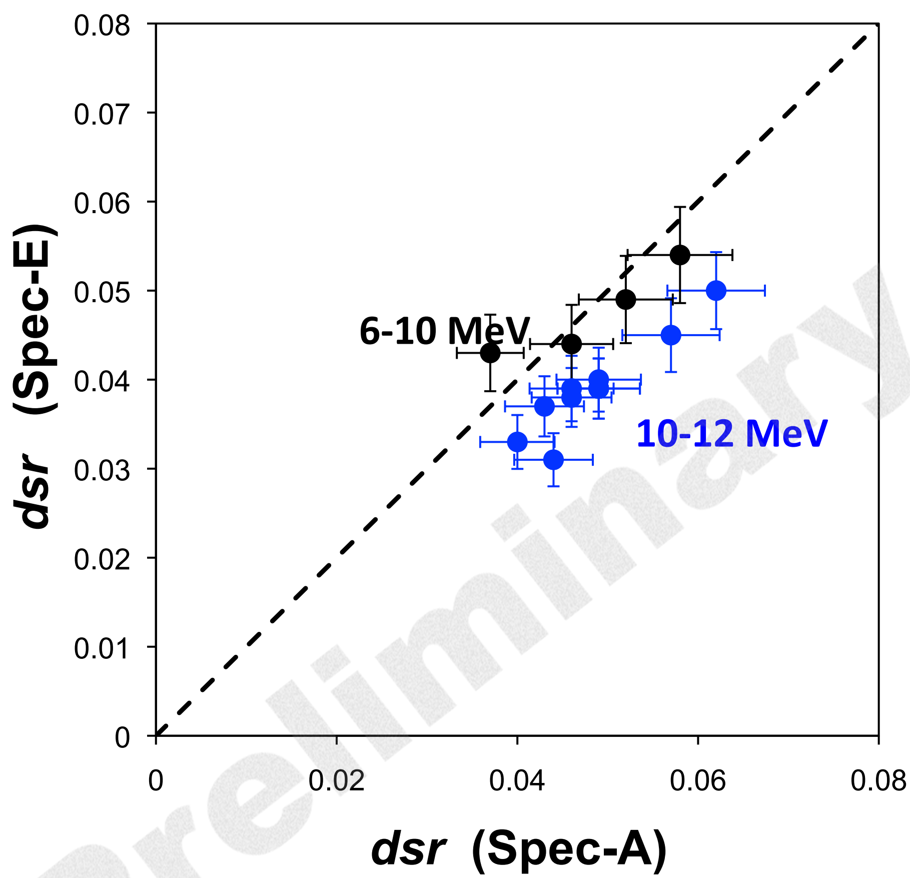
Outcome and Potential Impact

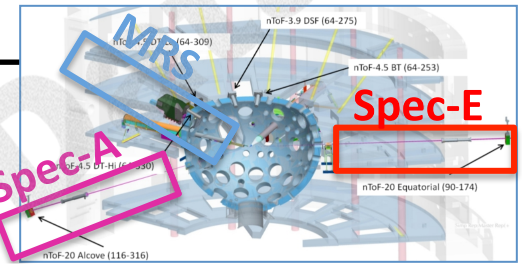
Reduce uncertainty in shock timing and 1D fuel assembly.

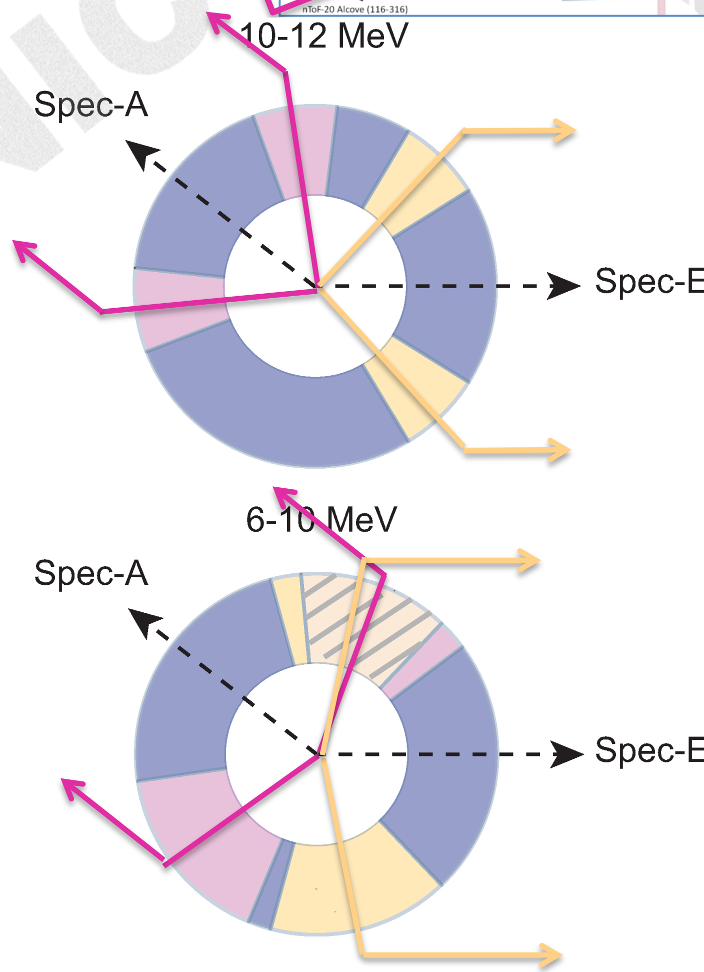
Eliminating a 1D explanation allows us to focus on 3D effects.

3D working group

The neutron spectrometry data indicate low-mode *ρR* asymmetries

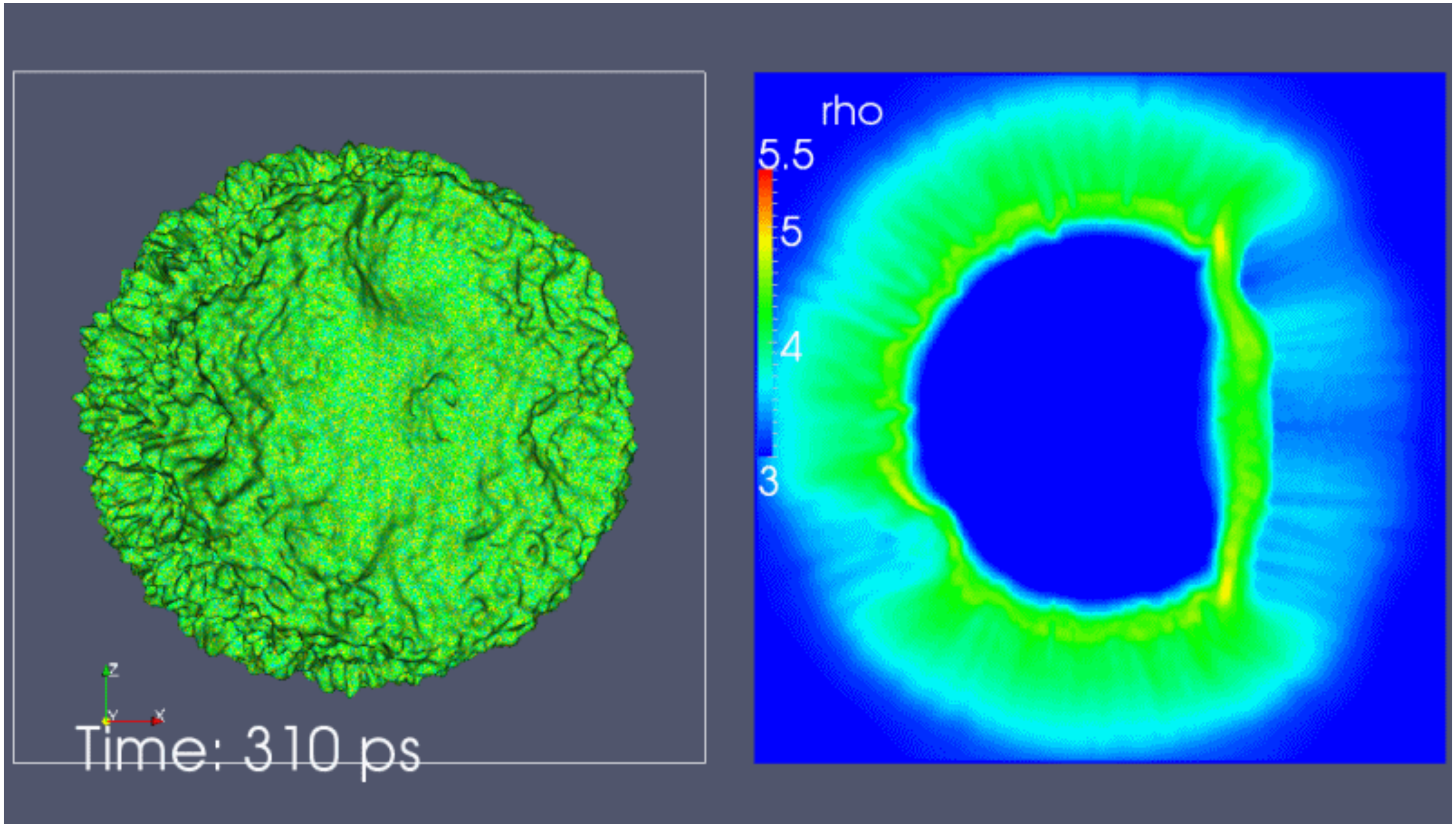






Perturbed 3D simulations (Chittenden) show that complex *ρR* structures might arise

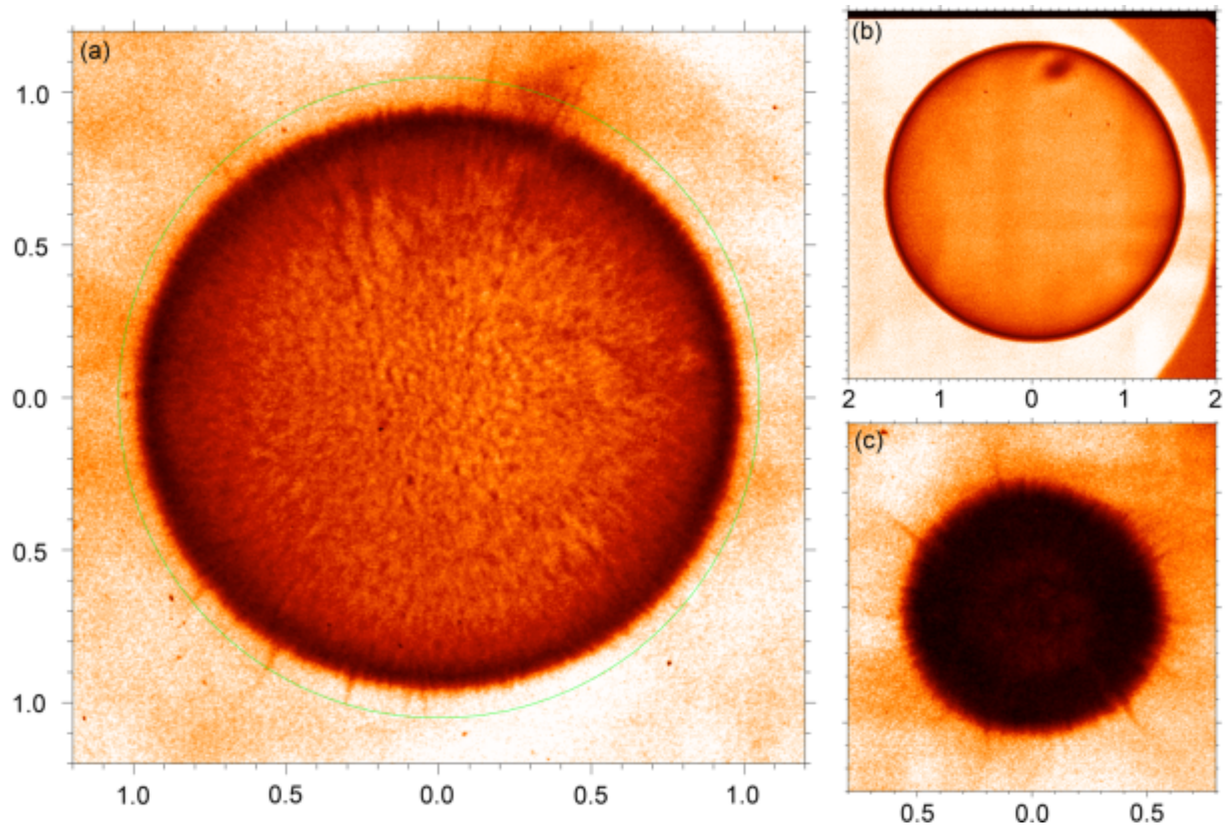
3D simulation with both high and low-mode perturbations



10 g/cm³ density surface | **Density slice**

3D working group

A 2D radiography capability would allow a direct measurement of ρR and the detailed implosion structure



In-flight radiographs of ICF implosions with isolated local defects. It is difficult to measure shell broadening and determine mode number of structures with 1D streak images.

M.E. Cuneo et al., IEEE Trans. Plasma Sci. 39, 2412 (2011).

3D working group

Stagnation and Burn
Stagnation in 3D

Underlying physics to be addressed

Significant ρR variations can arise during the acceleration phase and/or the deceleration (stagnation) phase.

Multiple possible origins: Non-uniform x-ray drive, geometrical asymmetry (tent, fill tube, offsets), capsule imperfections, sub-grid turbulence

Learned from NIC

- Long wave-length ρR asymmetries are observed by MRS, nTOF and FNADS dsr data.
- The implosions display varying levels of hydro instability.
- Springer model indicates a residual energy balance problem.

Research Directions

What can be done near term?

- 3D calculations encompassing broad range of perturbation scenarios.
- Need for experiments that are not fully-integrated, focused on specific hypotheses for the origin of ρR variations
- 2D radiography can directly measure ρR variations; useful for both early and late in implosion.

Outcome and Potential Impact

One impact is that the kinetic energy is not simultaneously converted into thermal energy, resulting in lower hot-spot pressure. Also the variations result in "weak spots" in shell where inertial confinement is not provided.

If we understand the origins of the variations we may be able to mitigate them and thereby improve hot-spot pressure.